TITLE OF THE INVENTION

DISPLAY DEVICE AND METHOD OF MANUFACTURING THE SAME

BACKGROUND OF THE INVENTION

1. Field of the Invention:

[0001]

The present invention relates to a display device which utilizes an emission of electrons into a vacuum, and more particularly, to a display device having high performance and high reliability which can control the position and the size of electron sources and, at the same time, can prevent the deterioration of characteristics of the electron sources and a fabrication method thereof.

[0002]

2. Description of the Related Art

As a display device which exhibits the high brightness and the high definition, color cathode ray tubes have been widely used conventionally. However, along with the recent request for the higher quality of images of information processing equipment or television broadcasting, the demand for planar displays (panel displays) which are light in weight and require a small space while exhibiting the high brightness and the high definition has been increasing. As typical examples, liquid crystal display devices, plasma display devices and the like have been put into practice. Further, particularly, as display

devices which can realize the higher brightness, it is expected that various kinds of panel-type display devices including a display device which utilizes an emission of electrons from electron sources into a vacuum (hereinafter, referred to as "an electron emission type display device" or "a field emission type display device") and an organic EL display which is characterized by low power consumption will be put into practice.

[0003]

Among such panel type display devices, as the above-mentioned field emission type display device, a display device having an electron emission structure which was invented by C. A. Spindt et al (for example, see USP 3453478 specification), a display device having an electron emission structure of a metal-insulator-metal (MIM) type, a display device having an electron emission structure which utilizes an electron emission phenomenon based on a quantum theory tunneling effect (also referred to as "surface conduction type electron source", see Japanese Unexamined Patent Publication 2000-21305, for example), and a display device which utilizes an electron emission phenomenon having a diamond film, a graphite film and carbon nanotubes and the like have been known.

[0004]

Fig. 11 is a cross-sectional view showing one constitutional example of a known field emission type display device. Fig. 12(a) and Fig. 12(b) are explanatory views showing

a constitutional example of an electron source of one pixel and a control electrode which controls an electron emission quantity of the electron source in the field emission type display device shown in Fig. 11, wherein Fig. 12(a) is a side view and Fig. 12(b) is a plan view. The field emission type display device is constituted such that between inner peripheries of both of a back panel 100 which forms field emission type electron sources and control electrodes on an inner surface thereof and a face panel 200 which includes anodes and fluorescent material layers on an inner surface thereof which faces the back panel 100 in an opposed manner, a sealing frame 300 is sealed by insertion so as to set a pressure of an inner space defined by the back panel 100, the face panel 200 and the sealing frame 300 to a value lower than an external pressure or to create a vacuum in the inner space (hereinafter referred to as "vacuum").

[0005]

The back panel 100 includes a plurality of cathode lines 2 having electron sources and control electrodes 4 which are configured to cross the cathode lines 2 by way of insulating layers 3 on one surface of a back substrate 1 which is preferably made of glass or ceramics. Then, in response to the potential difference between the cathode line 2 and the control electrode 4, an emission quantity (including turning on and off for emission) of electrons emitted from the electron source is controlled. Further, the face panel 200 includes anodes 7 and

fluorescent materials 6 on one face of a face substrate 5 made of a light transmissive material such as glass. The sealing frame 300 is fixed to the inner peripheries of the back panel 100 and the face panel 200 using an adhesive material such as frit glass. The inside which is formed among the back panel 100, the face panel 200 and the sealing frame 300 is evacuated at a degree of vacuum of 10^{-5} to 10^{-7} Torr, for example. A gap between the back panel 100 and the face panel 200 is held by gap holding members 9.

[0006]

The insulating layers 3 are interposed between the cathode lines 2 which are formed on the back substrate 1 of the back panel 100 and the control electrodes 4 which cross the cathode lines 2 and apertures (grid holes) 4a are formed in respective crossing portions of the control electrodes 4. On the other hand, the electron sources 2a are formed on the above-mentioned crossing portions of the cathode lines 2, while the insulating layer 3 is removed at portions of the cathode lines 2 which correspond to the apertures 4a formed in the control electrodes 4. The apertures 4a allow the electrons emitted from the electron sources 2a to pass therethrough to the anode side.

[0007]

The above-mentioned electron sources are, for example, constituted of carbon nanotubes (CNT), diamond-like carbons (DLC) or other field emission cathodes. Here, as the electron

sources, sources which use carbon nanotubes (hereinafter referred to as "CNT") are shown. As shown in Fig. 12(a) and Fig. 12(b), the electron source 2a is arranged right below the aperture 4a of the control electrode 4. Although one electron source 2a is allocated to each one pixel in Fig. 12(a) and Fig. 12(b), a plurality of electron sources 2a may be allocated to one pixel.

[0008]

Fig. 13(a) and Fig. 13(b) are explanatory views of a display device in which a plurality of electron sources are formed per one pixel and correspond to Fig. 12(a) and Fig. 12(b), wherein Fig. 13(a) is a side view and Fig. 13(b) is a plan view. That is, Fig. 13(a) and Fig. 13(b) show the constitution which form a plurality of small electron sources and small apertures per one pixel. Here, a plurality of small apertures 4a1 to 4aN are formed in the control electrode 4 and a plurality of small electron sources 2a1 to 2aN are formed on the cathode line 2 at positions corresponding to the respective small apertures. The electrons irradiated from the back panel 100 impinge on the fluorescent material 6 formed on the face panel 200 which faces the back panel 100 in an opposed manner. Then, light which responds to light emitting property of the fluorescent material 6 is irradiated to the outside of the face panel 200 so that the constitution functions as a display device.

[0009]

Fig. 14 is a schematic cross-sectional view for explaining another constitutional example of a known field emission type display device which includes one electron source and one aperture per one pixel. Further, Fig. 15 is an enlarged cross-sectional view of a portion indicated by A in Fig. 14. In Fig. 14 and Fig. 15, reference symbol 100 indicates a back panel, reference symbol 200 indicates a face panel and reference symbol 300 indicates a sealing frame. The back panel 100 includes cathode lines 2 which have electron sources 2a and control electrodes 4 which are provided in an insulated manner from the cathode lines 2 or an inner surface of the back substrate 1. In this example, the control electrodes 4 are held in a state that the above-mentioned insulating layer 3 is not interposed. Further, on an inner surface of a face substrate 5 which constitutes the face panel 100, fluorescent materials 6 and anodes 7 are formed in the same manner as the previously-mentioned display devices.

[0010]

The control electrode 4 has a function of controlling emission of electrons (pulling out of electrons) from the electron source 2a which is arranged on the cathode line 2. Further, in place of the control electrode 4 or in addition to the control electrode 4, it may be possible to adopt the constitution in which other electrode is provided for applying a potential which converges electrons to the fluorescent material

6. Although the fluorescent material 6 is formed on the anodes 7 in Fig. 14, there also exists the constitution in which the anode 7 covers the fluorescent material 6. Further, there also exists the constitution which provides a light shielding layer (black matrix) between the neighboring fluorescent materials 6. The back panel 100 and the face panel 200 are laminated to each other by a sealing frame 300 and a space defined between them is sealed in a vacuum.

[0011]

As shown in Fig. 15,electron sources 2a are formed on cathode lines 2 provided to the back panel 100. The electron source 2a is formed of an electron emitting material which efficiently generates electrons in response to an electric field applied between the cathode line 2 and the control electrode 4. With respect to a conductive material, in general, the sharper a shape of outside edges thereof which are exposed in the electric field, the conductive material exhibits the higher electron emitting performance. Accordingly, by adopting a fiber-like (rod-like) conductive material, it is possible to realize the highly efficient electron emission. As one of such electron emitting materials, the above-mentioned CNT exists.

[0012]

When the fiber-like conductive material is used as the material of the electron sources 2a, it is necessary to fix the conductive fibers on the cathode lines 2. Here, the explanation

is made with respect to a case in which the CNT is used as the fiber-like conductive material. The CNT is an extremely fine needle-like carbon compound (in a strict sense, a hollow substance in which a planar structure called graphene which is formed of carbon atoms arranged in a hexagonal shape is arranged in a cylindrical shape and is closed and has a diameter of nanometer scale). By arranging the CNT on the cathode line so as to use the CNT as the electron source, it is possible to obtain the efficient electron emission. In arranging the CNT on the cathode line, there has been known a method in which an electrode paste which is formed by mixing the CNT together with a conductive filler such as silver or nickel is applied to the cathode line to form an electron source layer and, thereafter, the electron source layer is baked to be fixed to the cathode line. Here, as publications which disclose the related art on this type of display device, for example, Japanese Unexamined Patent Publication 11-144652, Japanese Unexamined Patent Publication 2000-323078 and the like are named.

SUMMARY OF THE INVENTION

[0013]

In the above-mentioned conventional field emission type display device, electrons emitted from the electron source 2a pass through the aperture 4a and impinge on the fluorescent material 6 of the anode 7 and excite the fluorescent material

6 to emit light and to perform a display. Accordingly, the field emission type display device provides the excellent constitution which possesses the excellent characteristics such as high brightness and high definition and provides a planar display which is light-weighted and requires a small space for installation. However, in spite of such an excellent constitution, the display device still has drawbacks to be solved. That is, the electrons emitted from the electron source 2a flow into the control electrode 4 and hence, display efficiency is lowered. Further, when the control electrode 4 is made of a metallic material, it is necessary to solve a problem on heat dissipation besides the lowering of display efficiency.

[0014]

Further, it is difficult to ensure the alignment of the electron source 2a and the aperture 4a corresponding to the electron source 2a and this eventually promotes the above-mentioned lowering of display efficiency. Further, the CNT is deteriorated and dissipated due to heating during fabrication steps and hence, a sufficient electron emission quantity cannot be obtained and the formation of the electron source capable of uniformly emitting electrons is difficult. In this manner, the related art is not yet sufficient to put the display device into practice with respect to these drawbacks and the drawbacks constitute tasks to be solved.

[0015]

Accordingly, it is an object of the present invention to provide a display device which can solve the above-mentioned tasks of the related art and can exhibit high-performance electron emission characteristic and can prevent the deterioration of characteristics of electron sources and hence, can exhibit the high reliability and the long lifetime.

[0016]

To achieve the above-mentioned object, the display device according to the present invention is characterized by the constitution in which a plurality of small electron sources and small apertures are provided to each pixel and the small electron sources include boron (B) and also is characterized by the acquisition of alignment of the small electron sources with the small apertures corresponding to the small electron sources, by the acquisition of relative relationship between areas of the small electron sources and areas of the small apertures corresponding to the small electron sources, and by the suppression of the dissipation of CNT caused by heating during fabricating steps. To enumerate basic constitutions of the present invention, they are as follows.

[0017]

(1) The display device according to the present invention is provided with a back panel which includes a plurality of cathode lines, a plurality of electron sources which are arranged on the plurality of respective cathode lines, control electrodes

which are arranged to face the cathode lines in an opposed manner and control an emission quantity of electrons from the electron sources and a back substrate which holds the cathode lines, and a face panel which includes anodes and fluorescent materials. The control electrode includes a plurality of small apertures which allow electrons emitted from the electron sources to pass therethrough to the face panel side at regions which respectively face the each electron source, and each respective electron source is divided into a plurality of small electron sources corresponding to the plurality of respective small apertures, and boron (B) is contained in the small electron sources. Boron (B) is arranged on control-electrode-side surfaces of the small electron sources or on cathode-line-side surfaces of the small electron sources. Alternatively, boron (B) may be arranged on surfaces of the cathode lines with respect to a plurality of small electron sources in common.

[0018]

In this manner, by arranging the small electron sources containing boron corresponding to the small apertures formed in the control electrode, the inflow of the electrons to the control electrode can be reduced whereby it is possible to obtain the display device which has the excellent electron emission characteristic and prevents the deterioration of property of electron sources and hence can exhibit the high definition, high performance and high reliability. Here, the area of the small

electron source is set smaller than the area of the small aperture which corresponds to the small electron source.

[0019]

Due to such a constitution, the electrons which are radiated from the small electron sources pass through the small apertures in the anode direction without wasting the electrons and hence, it is possible to obtain images of high brightness with low power and, at the same time, a drawback on heat dissipation of the control electrode can be solved.

[0020]

(2) The display device according to the present invention is provided with a back panel which includes a plurality of cathode lines, a plurality of electron sources which are arranged on the plurality of respective cathode lines, control electrodes which are arranged to face the cathode lines in an opposed manner and control an emission quantity of electrons from the electron sources and a back substrate which holds the cathode lines, and a face panel which includes anodes and fluorescent materials. The control electrode includes a plurality of small apertures which allow electrons emitted from the electron sources to pass therethrough to the face panel side at regions thereof which respectively face the each electron source, and each respective electron source is divided into a plurality of small electron sources corresponding to the plurality of respective small apertures, and boron (B) is contained in the small electron

sources and the control electrodes. The control electrodes are made of a metal material.

[0021]

Due to such a constitution, the surfaces of the control electrodes are covered with boron (B) and hence, an undesired emission (grid emission) of electrons from the surfaces of the control electrodes can be suppressed and, at the same time, a drawback on the heat dissipation of the control electrodes can be solved.

[0022]

(3) Further, the display device according to the present invention is provided with a back panel which includes a plurality of cathode lines, a plurality of electron sources which are arranged on the plurality of respective cathode lines, control electrodes which are arranged to face the cathode lines in an opposed manner and control an emission quantity of electrons from the electron sources and a back substrate which holds the cathode lines, and a face panel which includes anodes and fluorescent materials. The control electrode includes a plurality of small apertures which allow electrons emitted from the electron sources to pass therethrough to the face panel side at regions which respectively face the each electron source and projecting portions which extend to the back substrate side at portions which differ from portions which face the cathode lines. Each electron source is divided into a plurality of small electron

sources corresponding to the plurality of respective small apertures, and assuming a distance between top surfaces of the small electron sources and bottom surfaces of the small apertures as "a" and a distance between inner surfaces of projecting portions and a side face of the small electron source closest to the inner surfaces of projecting portions as "b", a relationship $b \geq 2a$ is established. One ends of the projecting portions are brought into contact with the back substrate.

[0023]

Due to such a constitution, the dielectric strength property can be enhanced and the display efficiency is enhanced by suppressing the inflow of electrons into the control electrodes, and the control electrodes can be supported in a more stable manner as being supported by the projecting portions.

[0024]

(4) The fabrication of the above-mentioned display device according to the present invention includes a step for forming a plurality of cathode lines on a back substrate, a step for forming a plurality of electron sources to each cathode line, a step for adhering boron (B) to respective electron sources by way of masks each of which has a plurality of small openings corresponding to each electron source, and a step for forming portions of each electron source which correspond to the small openings and to which the boron (B) is adhered into small electron sources by heating each electron source.

[0025]

The control electrodes can be used as the masks and the electron sources are heated at a temperature of equal to or more than 450°C. By preventing the dissipation of the fiber-like conductive material such as CNT which constitutes the electron source, it is possible to obtain a sufficient electron emission quantity. Further, it is possible to constitute the electron source which emits the electrons uniformly and, at the same time, it is possible to obtain the display device which hardly suffers from the deterioration of the electron emission characteristic and hence enjoys the long lifetime. Further, the alignment between the small electron sources and the small apertures is ensured and hence, the display efficiency can be enhanced.

[0026]

With the use of this method, the heating operation is facilitated and hence, by preventing the dissipation of the fiber-like conductive material such as CNT which constitutes the electron source, it is possible to obtain a sufficient electron emission quantity. Further, it is possible to constitute the electron source which emits the electrons uniformly and, at the same time, it is possible to obtain the display device which hardly suffers from the deterioration of the electron emission characteristic and hence, enjoys the long lifetime.

[0027]

It is needless to say that the present invention is not limited to the above-mentioned constitutions and the constitutions of embodiments described later and various modifications are conceivable without departing from the technical concept of the present invention.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a developed perspective view of an essential part for explaining the constitution of one embodiment of a field emission type display device according to the present invention.

Fig. 2 is an enlarged schematic cross-sectional view of an essential part in Fig. 1.

Fig. 3(a) to Fig. 3(g) are enlarged cross-sectional views of an essential part for explaining constitutional examples of an electron source of the embodiment of the field emission type display device according to the present invention.

Fig. 4 is a cross-sectional view of an essential part of a display device for explaining a fabrication method of the field emission type display device according to the present invention.

Fig. 5 is a cross-sectional view of an essential part of a display device for explaining a fabrication method of the field emission type display device according to the present invention.

Fig. 6 is a schematic cross-sectional view of an essential part of a display device for explaining a fabrication method of the field emission type display device according to the present

invention.

Fig. 7 is a cross-sectional view of an essential part of a display device for explaining a fabrication method of the field emission type display device according to the present invention.

Fig. 8 is a cross-sectional view of an essential part for explaining the constitution of another embodiment of the field emission type display device according to the present invention.

Fig. 9 is a schematic perspective view for explaining one example of the holding structure for holding a given distance between a back substrate and a face substrate of the field emission type display device according to the present invention.

Fig. 10 is an equivalent circuit for explaining one example of a driving method of a display device according to the present invention.

Fig. 11 is a cross-sectional view for explaining a constitutional example of a conventional field emission type display device.

Fig. 12(a) and Fig. 12(b) are explanatory views of constitutional examples of an electron emitting source and a control electrode for controlling an electron emission quantity in one pixel of the conventional field emission type display device.

Fig. 13(a) and Fig. 13(b) are explanatory views corresponding to Fig. 12(a) and Fig. 12(b) in which a plurality of electron sources of the conventional field emission type

display device are formed per one pixel.

Fig. 14 is a schematic cross-sectional view for explaining another constitutional example of the conventional field emission type display device.

Fig. 15 is an enlarged cross-sectional view showing a portion indicated by A in Fig. 14.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0028]

Preferred embodiments of the present invention are explained in detail hereinafter in conjunction with drawings which show these embodiments. Fig. 1 is a developed perspective view showing an essential part for explaining the constitution of one example of the field emission type display device according to the present invention, wherein parts which are identical with the parts shown in the previously-mentioned drawings and parts which have the identical functions as those are given same symbols. In Fig. 1, reference symbol 1 indicates an electron-source-side back substrate, reference symbol 2 indicates cathode lines which hold electron sources, reference symbol 2a indicates electron sources. The electron sources 2a are arranged on a surface of the cathode line 2 at a plurality of positions spaced apart from each other with a given interval, and each electron source 2a is constituted of a mass of a plurality of small electron sources 2an. The plurality of small electron sources 2an are formed

on a surface of the cathode line 2 which is formed by preliminarily printing and baking a silver paste in a state that the small electron sources 2an contain silver (Ag), CNT and boron (B), while the electron source 2a contains boron (B).

[0029]

The small electron sources 2an are formed by a method which forms the small electron sources 2an by baking an Ag-B-CNT paste, for example or a method which separately adheres boron (B) or the like. Further, the reference symbol 4 indicates control electrodes (metal grids) formed of a metal plate. A plurality of control electrodes 4 are arranged in a spaced-apart manner at a given interval in the direction orthogonal to the cathode lines 2. A plurality of apertures 4a are formed in and arranged on each control electrode 4 at positions corresponding to the respective electron sources 2a. Each aperture 4a is constituted of a mass of small apertures 4an in number which corresponds to the number of the above-mentioned plurality of small electron sources 2an. Each small aperture 4an has an area which is substantially equal to an area of each small electron source 2an corresponding to each small aperture 4an and they are substantially aligned with each other. Further, a face-panel-5-side surface of the control electrode 4 is covered with a layer containing boron (B) (not shown in the drawing).

[0030]

Further, the reference symbol 4b indicates projecting

portions and these projecting portions 4b are positioned at a substantially center between the apertures 4a and project toward the back substrate 1 side. Distal ends of the projecting portions 4b are adhered to the back substrate 1 between cathode lines 2 by way of an adhesive agent such as glass frit or the like (not shown in the drawing). A distance between the small apertures 4an and the small electron sources 2an is defined by the projecting portions 4b and is set to approximately 25μm in this embodiment. Further, although the control electrodes 4 may preferably be made of an iron alloy (for example, 42%Ni - 6%Cr - balance Fe), the material of the control electrodes 4 is not limited to such a material.

[0031]

It is preferable to form the small apertures 4an by etching from a viewpoint of accuracy. Further, it is also possible to form the projecting portions 4b by etching. Still further, it is also possible to simultaneously form the small apertures 4an and the projecting portions 4b from both surfaces by etching. In the constitution of the embodiment shown in Fig. 1, one pixel is constituted of a plurality of small electron sources 2an and a plurality of small apertures 4an corresponding to the plurality of small electron sources 2an. Further, in the constitution shown in Fig. 1, different from the conventional control electrodes which are formed by sputtering, the control electrodes 4 are formed by machining plate materials and hence, there arises

an advantageous effect that the control electrodes 4 can be fabricated as separate members. Still further, since the face-substrate-5-side surface of the control electrode 4 is covered with a layer containing boron (B) (not shown in the drawing), the control electrode 4 has a discharge preventing effect.

[0032]

Fig. 2 is a schematic cross-sectional view showing an essential part of the display device according to the present invention shown in Fig. 1 in an enlarged form. Parts in the drawing which are identical to the parts shown in Fig. 1 are given same symbols. In Fig. 2, the respective small electron sources 2an are independently arranged at portions corresponding to the small apertures 4an on the cathode line 2. Surfaces of the small electron sources 2an and the face-panel-5-side surface of the control electrodes 4 are covered with layers 10 containing boron (B). A distance "a" between top faces 11 of the small electron sources 2an and bottom surfaces 12 of the small apertures 4an is defined by the projecting portions 4b of the control electrode 4. As described above, in this embodiment, the distance is set to approximately 25μm. Further, the distance "b" between the projecting portion 4b and the small electron source 2a closest to the projecting portion 4b is set to a size which maintains the relationship that the distance "b" is twice or more larger than the distance "a", that is, b ≥ 2a.

[0033]

By maintaining the relationship between the distance "a" and the distance "b", it is possible to make it difficult for an undesired current to flow in the control electrode 4 and hence, the display efficiency is enhanced. Further, in this embodiment, an area of the top face 11 of the small electron source 2an is set equal to or smaller than an opening area of the corresponding small aperture 4an and hence, the inflow of electrons into the control electrode is reduced due to the relative relationship between these areas.

[0034]

Fig. 3(a) to Fig. 3(g) are enlarged cross-sectional views for explaining constitutional examples of small electron sources 2an of the embodiment of the display device according to the present invention. Fig. 3(a) shows the constitutional example of the small electron source shown in Fig. 2 and Fig. 3(b) shows the constitutional example of the small electron source 2an which forms the layer 10 containing boron (B) on the cathode-line-2-side thereof. The constitutional example is characterized by preliminarily forming the layer 10 having the substantially same area as the small electron source 2an and containing boron (B) at a position on the surface of the cathode line 2 where the small electron source 2an is to be formed and overlapping the small electron source 2a on the layer 10 so as to prevent the dissipation of a fiber-like conductive material

such as CNT which constitutes an electron source.

[0035]

Fig. 3(c) shows the constitutional example of the small electron source 2an, wherein the layers 10 containing boron (B) are formed on the front and back surfaces of the small electron source 2an. Besides the effect for preventing the dissipation of the conductive material which is obtained in the same manner as the above-mentioned constitutional example shown in Fig. 3(a) and Fig. 3(b), this constitutional example also has an advantageous effect that it is possible to facilitate the formation of the small electron sources 2an of high accuracy by exercising the fabrication method described later. Fig. 3(d) to Fig. 3(g) show the constitutional examples of the electron source 2a in which the layer 10 containing boron (B) is preliminarily formed on the front surface of the cathode line 2 and the small electron source 2an is formed on the layer 10. Here, the layer 10 containing boron (B) can be formed by mixing boron (B) into a paste at the time of forming the cathode line 2 per se. Fig. 3(e) shows the constitutional example of the small electron source 2an, wherein the layer 10 containing boron (B) is formed on the front surface and the back surface of the small electron source 2an and also has an advantageous effect substantially equal to the advantageous effect obtained by the constitutional example of the small electron source 2an shown in Fig. 3(c). Further, the constitutional example of the small

electron source 2an shown in Fig. 3(f) can also have an advantage that the conductive material dissipation prevention effect can be further enhanced by encasing the conductive material with the layer 10.

[0036]

In the same manner, according to the constitutional example of the small electron source 2an shown in Fig. 3(g), by encasing the conductive material with the layer 10 containing boron (B) and by mixing the conductive material and boron (B), it is possible to have an advantage that the conductive material dissipation prevention effect can be further enhanced. Due to the above-mentioned constitutions shown in Fig. 3(a) to Fig. 3(g), it is possible to prevent the dissipation of the fiber-like conductive material such as CNT which constitutes the electron source and hence, it is possible to obtain a sufficient electron emission quantity and the uniform emission of electrons and, furthermore, the deterioration of the electron discharge property can be prevented.

[0037]

Fig. 4 to Fig. 7 are cross-sectional views of an essential part of the display device for explaining the fabrication method of the field emission type display device according to the present invention. First of all, as shown in Fig. 4, the cathode lines 2 are formed on the back substrate 1 formed of a glass plate by applying a silver (Ag) paste to the back substrate 1 and by

baking the silver paste. Thereafter, a paste for electron sources made of a material containing CNT and conductive fillers such as silver (Ag) or the like is printed on the cathode lines 2 and is heated at a temperature in a range of 300 to 350°C so as to decompose organic binders in the paste for electron sources thus forming an electron source layer 13.

[0038]

Although the above-mentioned heating is not indispensable, to obtain the remarkable boron (B) adhering effect in the succeeding step, it is desirable to decompose and eliminate the organic binders which cover the surface of the cathode lines 2. Further, in this step, it is also possible to form the electron source layer 13 by printing a paste which contains only CNT. Next, as shown in Fig. 5, the control electrodes 4 are set over the back substrate 1 as masks. That is, the control electrodes 4 are set such that a plurality of small apertures 4an formed in the control electrode 4 face the electron source layer 13 and the distal ends of the projecting portions 4b are brought into contact with the surface of the back substrate 1 and, thereafter, both of the control electrodes 4 and the back substrate 1 are temporarily fixed to each other.

[0039]

Further, in this step, after positioning both of the control electrodes 4 and the back substrate 1, both of them may be fixed to each other by heating them at a temperature in a

range of approximately 400°C to 450°C. Although the oxidation and dissipation of CNT start due to the coexistence with metal at the above-mentioned heating temperature of equal to or more than 450°C, since the fixing time using frit glass is completed within approximately 10 minutes, the deterioration of the electron emission characteristic is of a trace amount which can be substantially ignored. To obviate the deterioration of the electron emission characteristic such that no practical problem arises, it is possible to perform fixing of both of the control electrodes 4 and the back substrate 1 in a non-oxidizing atmosphere such as a nitrogen atmosphere. Further, in this step, it is also possible to use other masks in place of the control electrodes 4. It is also effective to use exclusive-use masks by taking mass productivity into consideration.

[0040]

On the other hand, the use of the control electrodes 4 which are incorporated into the product as mentioned previously has the characteristic that the alignment of the small apertures and the small electron sources corresponding to the small apertures, that is, the coaxial property or the alignment of areas, shapes of the small apertures and the small electron sources corresponding to the small apertures is facilitated. Subsequently, as shown in Fig. 6, boron (B) is scattered from a vapor deposition source 14. The scattered boron (B) material 14a passes through the above-mentioned face-substrate-5-side

surface of the control electrode 4 and the small apertures 4an and is adhered to respective surface portions of the electron source layer 13 which become the small electron sources 2an and forms the layer 10 containing boron on these surfaces. A method for scattering boron (B) may be a conventionally known method. Further, it is not always necessary that boron is adhered in a single form and may be adhered in various forms including boron oxide and boric acid. Further, it is unnecessary to remove impurities contained at the time of adhering provided that the impurities do not remarkably impede the electron emission per se from the CNT.

[0041]

Then, the above-mentioned structure is heated at a temperature of 450°C for 30 to 60 minutes. Due to this heat treatment, the CNT in the remaining portions of the electron source layer 13 excluding the small-electron-source-2an portions which are covered with the layer 10 containing boron are removed. That is, the small-electron-source-2an portions of the electron source layer 13 which are covered with the layer 10 containing boron suppress the oxidation of the CNT as the adhered boron per se is oxidized to form the boron oxide and form protective layers for the CNT and hence, the CNT remains. However, with respect to the peripheries of the electron source layer 13 which are not covered with the boron layer 10, the CNT in the whole layer or the CNT excluding the conductive fillers

is dissipated by heating and hence, the columnar small electron sources 2an are formed as shown in Fig. 7. Further, boron adhered to the control electrodes 4 is fixedly adhered to such portions. Here, Fig. 7 shows the constitution in which the conductive fillers remain in the peripheries of the small electron sources 2an.

[0042]

Here, the heating temperature may be determined by taking the composition of the electron source layer 13 and the like into consideration. However, since no restriction is imposed on the heating temperature during the fabrication steps even when the heating temperature is 450°C or more, it is possible to sufficiently maintain the desired electron emission efficiency. Further, the CNT which is protected by boron once exhibits the protection effect even with respect to the additional heating under atmosphere which follows thereafter. Even when the heating is performed under atmosphere again at a temperature of 450°C or more, the CNT exists in the fiber form. Further, the deterioration of the electron emission characteristic can be obviated. This implies that the CNT exhibits the resistance not only in the baking process of the printing paste but also in the succeeding heating process of the manufacturing steps and hence, a yield rate in the fabrication of panels and the reliability of products can be remarkably enhanced, and the lifetime of the display device can be prolonged.

[0043]

Due to the above-mentioned fabrication method, it is possible to selectively adhere the layer 10 containing boron to the control electrodes 4 at desired positions with desired area by way of the masks. Further, by combining the CNT oxidation suppression action which boron has with the above selective adhesion of layer 10, due to their coupled effect, it is possible to attain the self-alignment of the small apertures 4an and the small electron sources 2a and, at the same time, it is possible to adopt the desired heating temperature in the fabrication steps, whereby it is possible to obtain the excellent advantageous effects such as the acquisition of accurate alignment of the small apertures 4an and the small electron sources 2an, the acquisition of high electron emission efficiency, and the reduction of the inflow of undesired electrons into the control electrodes. Further, with the use of the control electrodes 4 as the masks, not to mention the acquisition of accurate alignment, the control of areas of the small electrons sources 2an is further facilitated.

[0044]

Fig. 8 is a schematic cross-sectional view of a portion of another embodiment of the field emission type display device according to the present invention corresponding to the portion shown in Fig. 2. The constitution shown in Fig. 8 is characterized by reducing the number of projecting portions 4b

compared to the constitution shown in Fig. 2. In this embodiment, the control electrode 4 is formed by striding over every two cathode lines 2. Also in this constitution, in the same manner as the constitution shown in Fig. 2, a distance "a" between the top faces 11 of the small electron sources 2an and the bottom faces 12 of the small apertures 4an is defined by the projecting portions 4b of the control electrodes 4 and is set to approximately 25μm also in this embodiment in the same manner as described above. Further, the distance "b" between the projecting portions 4b and the small electron source 2an closest to the projecting portions 4b is set to a size which maintains the relationship that the distance "b" is twice or more greater than the distance "a", that is, b ≥ 2a. By maintaining this relationship between the distance "b" and the distance "a", the flow of an undesired current into the control electrodes 4 becomes difficult and hence, the display efficiency is enhanced. Further, although the projecting portions 4b are formed such that the control electrode 4 strides over every two cathode lines 2 in an example shown in Fig. 8, by forming the projecting portions 4b such that the control electrode 4 strides over three cathode lines of three primary colors of red (R), green (G) and blue (B) for display, it is possible to expect the reduction of color difference.

[0045]

Fig. 9 is a schematic perspective view for explaining one

example of the holding structure for holding a given distance between the back substrate 1 arranged at the electron source side of the display device of the present invention and the face substrate 5 arranged at the fluorescent face side of the display device of the present invention. Between the electron-source-side back substrate 1 on which the above-mentioned cathode lines 2, electron sources 2a and control electrodes 4 are formed and the fluorescent-face-side face substrate 5, partition walls (or spacers) 9 are interposed and peripheries of both substrates 1, 5 are sealed by a frame glass (not shown in the drawing) and glass frit (not shown in the drawing). This sealing is performed in the atmosphere at a temperature of 430°C. Thereafter, a space defined between both substrates 1, 5 is evacuated and is sealed in vacuum while heating the holding structure at a temperature of 350°C.

[0046]

Fig. 10 is an equivalent circuit for explaining one example of a driving method of the display device according to the present invention. In this display device, n pieces of cathode lines (electron source lines) 2 which extend in the y direction are juxtaposed in the x direction. Further, m pieces of control electrodes (metal grids) 4 which extend in the x direction are juxtaposed in the y direction thus constituting a matrix of m rows and n columns together with the cathode lines 2. On peripheries of the electron-source-side back substrate which

constitutes the display device, a scanning circuit 60 and a video signal circuit 50 are arranged. Respective control electrodes 4 are connected with the scanning circuit 60 at control electrode terminals 40 (Y1, Y2, … Ym). Respective cathode lines 2 are connected with the video signal circuit 50 at cathode terminals 20 (X1, X2, … Xn).

[0047]

For every pixel arranged at each one of crossing portions of the cathode lines 2 and the control electrodes 4 which are arranged in a matrix array, the electron source which is formed of a mass of a plurality of small electron sources containing boron explained in the above-mentioned embodiment is provided. In the drawing, R, G, B respectively indicate monochromatic pixels of red (R), green (G) and blue (B) each of which constitutes one pixel of each color. These respective monochromatic pixels emit lights corresponding to respective colors from the fluorescent materials. To the scanning circuit 60 and the video signal circuit 50, various signals for display are supplied from a host computer not shown in the drawing. Synchronizing signals 61 are also inputted to the scanning circuit 60. The scanning circuit 60 selects the row of the matrix of the control electrodes 4 through the control electrode terminals 40 and applies scanning signal voltages to the control electrodes 4.

[0048]

On the other hand, video signals 51 are inputted to the

video signal circuit 50. The video signal circuit 50 is connected to the cathode lines 2 through the cathode terminals 20 (X1, X2, ... Xn) and selects the column of the matrix and applies voltages corresponding to the video signals 51 to the selected cathode lines 2. Accordingly, given pixels which are sequentially selected by the control electrodes 4 and the cathode lines 2 emit lights in given colors thus displaying two-dimensional images. With the use of the display device which uses the CNT according to this constitutional embodiment as the electron source, it is possible to realize the bright display device which is operated with a relatively low voltage at high efficiency and can suppress the display irregularities.

[0049]

Here, although the explanation is made using the CNT (multi-wall CNT and single-wall CNT, carbon nanotubes in a broad meaning) as the electron emission material in the embodiment of the present invention, any material can obtain a similar advantageous effect as the electron irradiation material provided that the material is inorganic carbon material. As the inorganic carbon material other than the CNT, for example, diamond, diamond-like carbon, graphite, amorphous carbon can be used. Alternatively, a mixture of these materials can be also used as the electron irradiation material. Further, it is needless to say that the present invention is not limited to the constitutions of the above-mentioned embodiments and

various modifications can be made within the scope of the technical concept of the present invention.

[0050]

As has been described heretofore, according to the typical embodiment of the present invention, the display device constitutes one pixel by combining the plurality of small apertures and the plurality of small electron sources. Due to such a constitution, the small electron sources having the desired area can be formed in the given regions and hence, the inflow of electrons to the control electrodes can be reduced and, at the same time, the alignment of the small electron sources and the small apertures can be easily acquired. Further, the present invention can also exhibit other advantageous effects such as the acquisition of the high-performance electron emission characteristic, the prevention of the deterioration of characteristics of the electron sources whereby the display device of high definition, high performance and high reliability can be realized.

[0051]

Further, the heat resistance of the carbon nanotubes can be enhanced and hence, it is possible to elevate the heating temperature in the electron source baking step and the substrate sealing step in the fabrication process to the given high temperature whereby it is possible to realize the display device having the long lifetime which exhibits high-performance

electron emission characteristic and can prevent the deterioration of characteristics of the electron sources.

[0052]

Further, it is possible to use a general-use heating furnace (or a baking furnace) in the heating step of the fabrication process and this contributes to the reduction of fabrication cost. Further, by also adopting heating or baking in a non-oxidizing atmosphere in combination, the uniformity of the electron emission can be further enhanced whereby it is possible to provide the display device of high quality.